Volume Scattering From Corn And Wheat Canopies at 32GHz

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***Abstract*- The relationship between 32GHz backscatter measurements and wheat biomass and the underlying soil moisture content are investigated in this study. The received backscattered field deviates by about on the average of 2 dB between 0^0 and 20^0 of incident angle during a season. It is also represented that 00 responses is the most significant one as expected. The paper describes the experiment and investigates the radar sensitivity to biophysical parameters at different polarizations and incidence angle at different wheat phonological stages. Based on the experimental results, volumetric moisture content of soil contribution plays an important role in scattering phenomena and on radar cross section of canopies.**

Keywords—biomass retrieval, soil moisture retrieval, soil scattering, synthetic aperture radar (SAR), wheat scattering.

I. INTRODUCTION (*HEADING 1*)

Recent advances in remote sensing have demonstrated the ability to measure the spatial variation of soil moisture content in the near-surface layer under a variety of topographic and land cover conditions using both active and passive microwave measurements [1,2,3, 4 and 5]. However, one important difference between space borne active and passive microwave remote sensing systems is the resolution of the resulting data. Active sensors have capability to provide high spatial resolution, in the order of tens of meters, but are more sensitive to surface roughness, topographic features and vegetation than passive systems. Briefly one may say that soil moisture inversion from a single frequency, single polarization backscattering observation is difficult.

Mattia et al[1] aimed to investigate the sensitivity of C-band backscatter to changes in wheat canopy characteristics and soil moisture during the growing season. The sensitivity of radar data at C band, for both HH and VV polarizations for biophysical parameters (especially the underlying soil moisture and above-ground biomass) has been analyzed. The relationship between the radar and biophysical measurements was found to be considerably influenced by the dynamics of the canopy structure, which depends on the wheat phonological stage.

Bush [2] studied the radar backscatter coefficient σ0 of alfalfa as a function of both radar parameters and physical characteristics of the alfalfa canopy. He noted that the successful application of radar remote sensing techniques requires understanding electrical and geometrical properties of the remotely sensed scene. The acquisition of backscatter data over a wide range of the measurable target parameters and the construction of theoretical and empirical models are required for establishing such a relationship. The purpose of these studies in general is to estimate the soil moisture and important vegetation variables, such as leaf area index (LAI: m /m) and biomass (kg/m). This process let us to identify [6] a suitable radar configuration, and a relationship between the backscatter coefficient and the field variables. Gómez-Danset al [4] presented results from experiments carried out in the ground-based synthetic aperture radar (GB-SAR) facility at the University of Sheffield to ascertain the role of polarimetric interferometry in crop height retrieval.

Ulaby et al [3,7] studied radar response to vegetation at 8-18GHz Band. He reported that although soil moisture could be sensed through vegetation, the sensitivity of radar backscatter to soil moisture is quite dependent on vegetation characteristics and sensor parameter. Shu-Qing Li[8]assumed a vegetation canopy as a discrete random medium composed of scattering elements, such as trunks, stems, branches, and leaves, which can be modeled by canonical geometries, and assumed a certain dielectric constant for canopy which has also been studied by Chin-Yuan [9], and has represented the backscattering enhancement due to the volume surface interaction in a vegetation canopy consisting of leaves by the Monte Carlo simulations at 1.5GHz and 4.5GHz respectively. He presented that the angular width of the enhancement not only relates to the layer thickness, but also to the excitation frequency and such an angular width could be important for remote-sensing applications.

Jeffrey P. Walker et al[10] noted that SAR backscattering observations are highly dependent on topography, soil texture, surface roughness and soil moisture. They presented semi empirical and empirical formulas concerning soil moisture and roughness data, and reported a RMS correlation error of 0.5 to 2dB. They reported that the amount of absorption is primarily a result of the water content of the vegetation, whereas the scattering is influenced by the vegetation shape and geometry.

Narayan[11] studied the baseband power spectral density characteristic of X-band radar backscatter from wind-influenced vegetation. They proposed an empirical model taking into account both branch vibration and leaf/needle flutter. Frate et al[12] described an algorithm for predicting the soil moisture and the growth cycle of wheat fields using radar data. The algorithm is based on neural networks trained by model simulations and multi temporal ground data measured on fields taken as a reference.

Parameters including crop biomass and moisture have been particular interests in recent years, since those are market oriented mains. It is necessary to develop a model that describes the correlation between backscattering coefficient and biophysical parameters of plants. In order to complete this correlation, how vegetation responds to microwave energy is a necessity. So, this paper tries to modify an empiric formula generated by Bush [2] and Ulaby [3-7] to understand response of corn and wheat to radar signals, and obtaining angular dependent of backscattered field at 32 GHz.

II. MEASUREMENT COMPAIGN

Two data sets, one from wheat and one from corn, are considered in this work. Plants were grown at two neighbor fields having an area of $4x4=16m^2$ simulated in Fig1. Ground data covered some significant parameters such as soil moisture, soil roughness, crop height, crop biomass, etc.

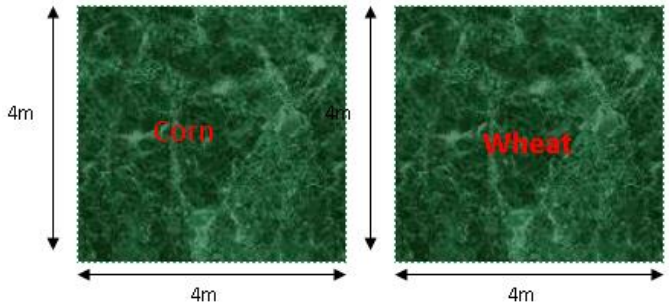


Figure 1. Plant area.

Table1 describes the properties of the system drawn in Fig.2. System contains a balcony-mounted scanning frame holding antennas, with one transmit and one receiving antennas. Both vertical (V) and horizontal (H) polarizations are applicable. Setup was established at the balcony of third floor which is about 12m above the ground level. Calibration to radar cross section (RCS) is based on measurements of a sphere and a depolarizing target, as described in [13]. A constructed railway system is in 15m length parallel to the building roof. A 6m leg of the system is carrying a radar, beam width of 10^0 and resolution of 5^0, has a rotation capability of 50^o from the origin. Above the balcony, seven different measurement points were chosen at every 50cm apart from each other. That means we have $L_{balcony}$/step=15/0.5=30 measurement points through x direction. For each measurement, radar was step a way through the end of leg at every 25cm that L_{leg}/ystep=4/0.25=16 measurement points are evaluable results in 30 by 16 matrices. For each of this (x, y) coordinates, radar was turned around from -50^0 to 50^0 by 5^0 steps that gives us 21 measurement step. Finally, daily measurement process includes 30x16x21=10080 data set/measurement. Collected data were superposed and analyzed after noise reduction techniques were applied to the system.

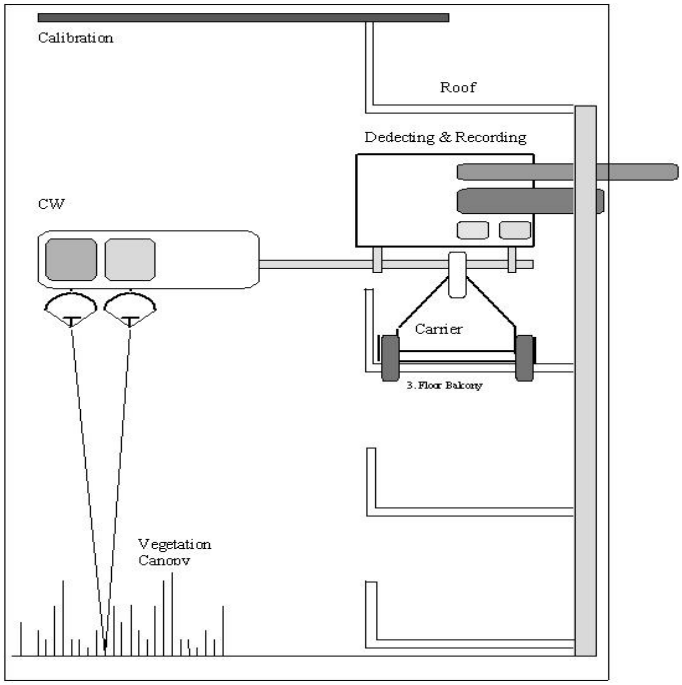


Figure 2. Measurement System.

Table.1 Specifications of the Measurement System

	Transmitter	**Receiver**
Type	CW Doppler	Radiometer
Polarization	Vertical	Vertical
Frequency	32 GHz	32 GHz
Positioning	Elevation	Elevation
Antenna	Cassegrain	Cassegrain
Height	10 m	10 m
Reflector Diameter	30 cm	30 cm
Feed	Pyramidal horn	Corrugated conic
Band Width	80MHz	80MHz

III. MODEL DESCRIPTION

Plant water content PWC is the dominant factor on reflectivity of vegetation canopies, instead a canopy is composed of more than 99% air by volume [9, 14]. Scattering from canopies depends on several factors including the penetration depth, the height of the canopy, frequency, and the incident angle that an incident angle plays an important role especially in backscattering effect. The highest correlation was obtained with the normalized water content $nPWC$. The incident angle plays an especially important role in backscattering as described in Eq.1.

$$nPWC = \frac{m_w - m_d}{h} \quad (1)$$

where h is the plant height, m_w and m_d are wet and dry mass of one individual plant. If we let n equal the number of plants per unit area of field then equation 1 becomes

$$nPWC = \frac{m_w - m_d}{nh} \quad (2)$$

An electromagnetic wave impinging on to the vegetation canopy splits into three parts as scattered, absorbed and backscattered part. Geometry of wave behavior is represented at Fig.3.

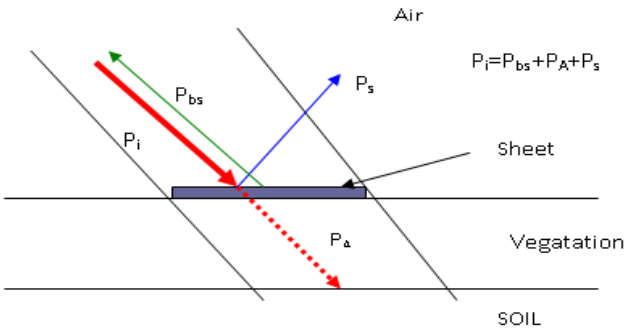


Figure 3. Geometry of the problem

The reflectivity factor is described as $\eta = N\sigma\ \eta$ (the radar-cross section per unit volume) and power coefficient factor is described as $\alpha = NQ$ per unit length that N is the number of water particles per unit volume, σ is the radar-cross section for a single element and Q is the total attenuation cross-section for a single element. Averaged scattered power can be obtained by integrating the incident power P_i with two-way attenuation factor of canopy layer as in Eq.3.

$$P_r = P_i . \int_0^{h.\sec\theta} \eta e^{-2\alpha z} dz \quad (3)$$

where W_i is the power density of incident wave and A is the illuminated area.

$$P_i = W_i . A . \cos\theta \quad (4)$$

Finally, the scattered coefficient of vegetation canopy, can be expressed as the ratio of an average scattered power to the incident power as described in Eq.5.

$$S_{veg} = \frac{P_r}{P_i} = \left(\frac{\sigma}{2Q}\right)\left[1 - e\exp\left(-2NQh.\sec\theta\right)\right] \quad (5)$$

Scattering from soil can be modeled (approximated) as in Eq.6.

$$S_{soil} = A.e^{B}.m_s \quad (6)$$

Where A and B are constants at a given frequency, polarization, angle of incidence and soil surface roughness, and m_s is the volumetric soil moisture content. Final model equation can be written as in Eq.7.

$$S = S_{soil} + S_{veg} \quad (7a)$$

$$S = \left[1 - e^{-D(nPWC).h\sec\theta}\right] + A'.m_s.e^{-D(nPWC).h\sec\theta} \quad (7b)$$

where the parameters are, $C = \frac{\sigma}{2Q}$, $D = \frac{2NQ}{wc_n}$ and $A' = A.e^{B}$.

A. *Acquiring The Model Parameters*

In order to determine the model parameters C, D and A', linear regression analysis was applied to the experimental data. During the regression; parameter D is chosen for minimum error, parameter D is defined, parameters A and C are found by Pseudo inverse method. The standard error of estimate (SEE) and the linear correlation coefficient c_l, between observed and predicted data, can expressed as in Eq. 8 and Eq.9. In those equations, σ^0(dB0) represents observed radar cross section and σ^0(dBP) represents predicted radar cross section per unit area while N represents the number of observations.

$$SEE_{dB} = \left(\frac{\sum\left[\sigma^0(dB0) - \sigma^0(dBP)\right]^2}{N}\right)^{1/2} \quad (8)$$

σ^0 (O) is observed value and σ^0 (P) predicted value of the radar cross section per unit area as expressed in real numbers(m^2/m^2), and M is the mean value. Regression analysis results are given in Table 2.

$$c_l = \left(1 - \frac{\sum\left[\sigma^0(0) - \sigma^0(P)\right]^2}{\sum\left[\sigma^0(0) - \sigma^0(Mean)\right]^2}\right)^{1/2} \quad (9)$$

Table.2 Regression analysis results.

CONSTANT	**WHEAT**	**CORN**
D(dB)	-0,166	-0,15
C(dB)	7,13	6,12
SEE(dB)	3,2	4,15
c_l	0,6938	0,5277

IV. RESULTS AND CONCLUSIONS

Roughness of the soil layer directly effect the scattering mechanism, and scattered data strongly correlated with the soil time histogram given in Fig4. Fig.4 represents both volumetric moisture content of relevant canopies and their height variation by in time index. Volumetric moisture content of wheat goes from about 8 to 0.8. That means initial value is about 10 times

bigger then crop time and variation is 5 times from initial to crop time for corn. In this time interval, height of wheat increase by about 10 times, and height of corn increase by 2 times. Inversely proportional to its height, water content of them drops by about ten times of initial values.

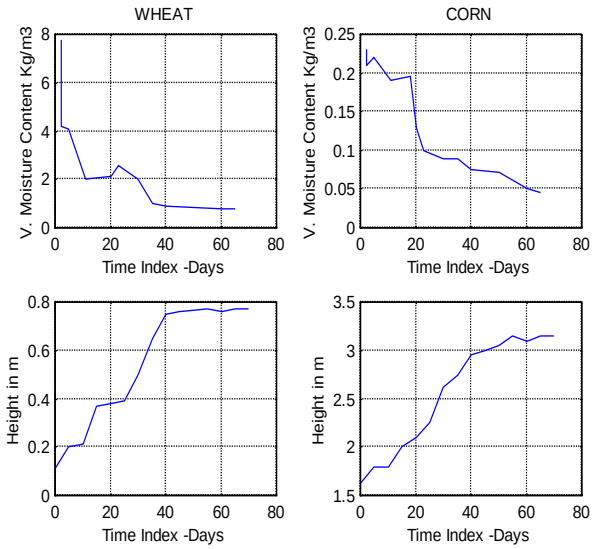
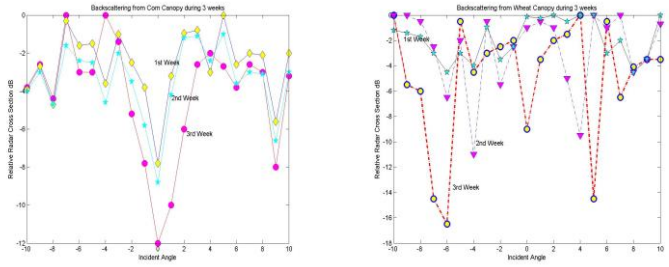


Figure 4. Moisture content and height variation versus time.



a) Wheat *b) corn*

Figure5 . Back scattering cross section of corn canopy. Measurements include three following week responses.

Figure 5a represents data obtained during three following weeks while canopies are growing. As mentioned before during this three weeks' time interval, moisture content decreased by ½ of initial value and height of corn increased by 40% of initial height. For corn canopies, backscattering response keeps its general shape during three weeks with an exception of amplitude. As seen from the Fig.5 that, there is one main lobe at normal and two symmetric lobes around 8^0 from the center. While corn is growing and losing moisture content of it, lobes are going up and shape closes to smooth compared to first week measurements. That means radar response strength decreases, this is because of dielectric permittivity closes air permittivity that most of the power transmitted and/or absorbed by it that no more reflection occurs.

Figure 5b represents data obtained during three following weeks while canopies are growing. As mentioned before during this three weeks' time interval, moisture content decreased by ¾ of initial value and height of wheat changed by 2 times the initial height. As seen from the figure 5 that, there is one main lobe at normal and two symmetric lobes around 8^0 from the center. While corn is growing and losing moisture content of it, lobes are going up and shape closes to smooth compared to first week measurements. That means radar response strength decreases, this because of dielectric permittivity closes air permittivity that most of the power transmitted and/or absorbed by it that no more reflection occurs. Figure 6 represents the same responses for wheat canopy. This case two side lobes goes deeper while growing. And the response of wheat becomes much smoother than the corn canopies. Correlation coefficients need to be determined in the formula are calculated by daily measurements during summer time. Fig.6 represents the value of factor A with respect to angle of incidence for both canopy of corn and wheat. Fig.7a includes the representation for the factor C and Fig.7b includes soil variation of relevant canopy area by in time index. It is seen soil contribution for both canopy layers increases during first 4-5weeks and then start to decrease up to getting ¼ of initial value.

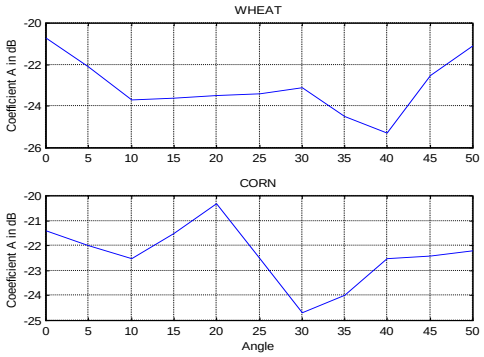


Figure 6. Variation of Coefficient A

For a vegetation of corn and wheat canopies, a volume scattering model including the non-coherent effect of soil surface scattering was developed as a water cloud. With this model, it is not only possible to predict σ^0 for any set of ground-truth data, but also possible to predict the attenuation in vegetation layer, and σ^0 of soil, relative to observed radar cross section. Although this model provides an adequate description of overall behavior of backscattering coefficient of vegetation canopy as a function of incident angle and moisture content of plant and soil, because of the startup assumptions, there is still some error. Model does not account the effect of plant geometry. Additionally, as formulated, this model treats the entire canopy as having same characteristic over its height h, which generally is not true. The model can provide us distinguishing the canopy area from the soil area. Model also gives us a sound for understanding of the physics of radar scattering by vegetation canopies

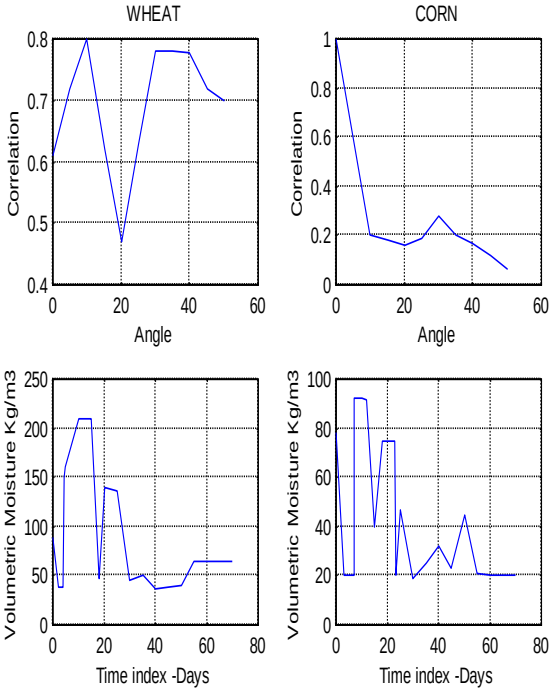


Figure 7. Variation of Correlation Coefficient "C_l" and Time variation of the soil contribution for canopies

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